SOCIETAL LCA

Social life cycle assessment for material selection: a case study of building materials

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Abstract

Purpose Sustainability of a material-based product mainly depends on the materials used for the product itself or during its lifetime. A material selection decision should not only capture the functional performance required but should also consider the economical, social, and environmental impacts originated during the product life cycle. There is a need to assess social impacts of materials along the full life cycle, not only to be able to address the "social dimension" in sustainable material selection but also for potentially improving the circumstances of affected stakeholders. This paper presents the method and a case study of social life cycle assessment (S-LCA) specialized for comparative studies. Although the authors' focus is on material selection, the proposed methodology can be used for comparative assessment of products in general.

Methods The method is based on UNEP/SETAC "guidelines for social life-cycle assessment of products" and includes four main phases: goal and scope definition, life cycle inventory analysis, life cycle impact assessment, and life cycle interpretation. However, some special features are presented to adjust the framework for materials comparison purpose. In life cycle inventory analysis phase, a hot spot assessment is carried out using material flow analysis and stakeholder and experts' interviews. Based on the results of that, a pairwise comparison method is proposed for life cycle impact assessment applying analytic hierarchy process. A case study was conducted to perform a comparative assessment of the social and socio-economic impacts in life cycle of concrete and steel as building materials in Iran. For hot spot analysis, generic and national level data were gathered, and for impact assessment phase, site-specific data were used.

Result and discussion The unique feature of the proposed method compared with other works in S-LCA is its specialty to materials and products comparison. This leads to some differences in methodological issues of S-LCA that are explained in the paper in detail. The case study results assert that "steel/iron" in the north of Iran generally has the better social performance than "concrete/cement." However, steel is associated with many negative social effects in some subcategories, e.g., freedom of association, fair salary, and occupational health in extraction phase. Against, social profile of concrete and cement industry is damaged mainly due to the negative impact of cement production on safe and healthy living condition. The case study presented in this article shows that the evaluation of social impacts is possible, even if the assessment is always affected by subjective value systems.

Conclusions Application of the UNEP/SETAC guidelines in comparative studies can be encouraged based on the results of this paper. It enables a hotspot assessment of the social and socio-economic impacts in life cycle of alternative materials. This research showed that the development of a specialized S-LCA approach for materials and products comparison is well underway although many challenges still persist. Particularly characterization method in life cycle impact assessment phase is challenging. The findings of this case study pointed out that social impacts are primarily connected to the conduct of companies and less with processes and materials in general. These findings confirm the results of Dreyer et al. (Int J Life Cycle Assess 11(2):88–97, 2006). The proposed approach aims not only to identify the best socially sustainable

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alternative but also to reveal product/process improvement potentials to facilitate companies to act socially compatible. It will be interesting to apply the UNEP/SETAC approach of S-LCA to other materials and products; materials with a more complex life cycle will be a special challenge. As with any new method, getting experience on data collection and evaluation, building a data base, integrating the method in software tools, and finding ways for effective communication of results are important steps until integrating S-LCA in routine decision support.

Keywords Analytic hierarchy process (AHP) · Material flow analysis (MFA) · Material selection · Pairwise comparison · Social hotspot analysis · Social life cycle assessment (S-LCA)

1 Introduction

The concept of sustainable development as is known today emerged in the 1980s as a response to the destructive social and environmental effects of the predominant approach to "economic growth." One of the earliest formulations of the concept of sustainable development is as follows: "For development to be sustainable, it must take account of social and ecological factors, as well as economic ones; of the living and non-living resource base; and of the long-term as well as the short-term advantages and disadvantages of alternative actions" (Azapagic et al. 2004). The World Commission on Environment and Development (WCED) brought the concept of sustainability to global prominence in "Our Common Future" that described sustainable development as "meeting the needs of the present without compromising the ability of future generations to meet their needs" (WCED 1987). From a business perspective, the concepts of sustainability are often described as the triple bottom line: (Abraham 2006)

- Economic viability: the business aspects of a development project,
- Social concerns: human health and social welfare,
- Natural or ecological issues: environmental stewardship.

As an instrument of sustainable development, sustainable design intends to conceive of products, processes, and services that meet the needs of society while striking a balance between economic and environmental interests (Jeswiet 2007). One of the aspects of sustainable design is sustainable product design. The three major topics of product design are material selection, part design, and assembly design. As a part of product design, materials selection is a multidisciplinary activity, which integrates a large number of knowledge fields and professional domains. Ljungberg (2007) stated that there are today at least four basic problems related to materials, which are more or less unsolved: over-consumption, resource utilization, pollution, and overpopulation. He emphasized that

sustainability of a material-based product is mainly dependent on the materials used for the product itself or during its lifetime. A material selection decision should not only capture the functional performance required for a special application but should also consider the economical, social, and environmental impacts originated during the product life cycle.

Since no development can be stable at the long run without social justice, social life cycle assessment (S-LCA) has also to be developed and considered. In the UNEP/SETAC guideline for S-LCA (simply will be referred as UNEP/SETAC guideline hereafter in the text), S-LCA is defined as a social impact (and potential impact) assessment technique that aims to assess the social and socioeconomic aspects of products and their potential positive and negative impacts along their life cycle (Benoît and Mazijn 2009). S-LCA complements E-LCA with social and socio-economic aspects. It can either be applied on its own or in combination with E-LCA. There is a need to assess social impacts of materials along the full life cycle, not only to be able to address the "social dimension" in sustainable material selection but also for potentially improving the circumstances of affected stakeholders. This paper presents the method and a case study of comparative S-LCA for material selection. Obviously, for sustainable material selection, social dimension that is presented in this paper should be combined with technical, economical, and environmental ones presented in other references such as Ashby (1999; 2009).

The rest of this paper is organized as follows: In Section 2, the literature review is presented. In Section 3, the proposed method is explained. In Section 4, a case study of the proposed method is reported. Finally, in Section 5, conclusions are made and future directions for research are suggested.

2 Literature review

There have been a few efforts directed at integrating social aspects into a life cycle format in the past decade. Most notable ones are O'Brien et al. (1996), Schmidt et al. (2004), Dreyer et al. (2006), Hunkeler (2006), Norris (2006), Weidema (2006), Reitinger et al. (2011), and Lagarde and Macombe (2013). Jørgensen et al. (2008) reviewed most of the current S-LCA literature. The approach of O'Brien et al (1996) supplements environmental LCA by identifying social and political factors that contribute to environmental issues. The framework suggested by Dreyer et al. (2006) seeks to become a corporate decision-making tool and incorporates the impacts of products and services on people, specifically promoting human health, human dignity, and basic needs fulfillment. Norris (2006) proposed a methodology to examine the benefits and damages to human health due to changes in gross national product per capita and the associated changes in pollution production. Hunkeler's technique is based upon

existing life cycle inventory data and enables product comparisons using regional level data to identify differences in employment per functional unit relative to work hours required to meet basic needs. Schmidt et al (2004) proposed a method to perform and present "socio-eco-efficiency" analysis that corresponds to BASF's eco-efficiency analysis and compared environmental and social performance to economic costs. Reitinger et al (2011) described the area of protection, namely the general concept of human well-being and the impact categories in SLCA in detail. Recently, Lagarde and Macombe (2013) proposed rules to identify the organizations involved in the social life cycle of a product within a context of competition. Once these organizations are identified, it is possible to deduce which groups are affected. Practical applications of S-LCA are presently limited (for example, Ekener-Petersen and Finnveden 2013; Lagarde and Macombe 2013).

Table 1 summarizes the related literature. Published works are classified into three major categories: methodology, literature review/survey, and case study/applications. However, a work may include contributions to methodology and report an application. Some research works are dedicated to reviewing other researches. Case study/application works are then classified into two major classes: simple and comparative studies. Table 1 also shows the characteristic of this work and displays its position among related publications. As will be clarified soon, the main goal of this paper is to develop a methodology for comparative S-LCA in general. Although the authors' focus is on material selection, the proposed methodology can be used for comparative assessment of products in general. The focus of this work is on comparison of two or more alternative materials for an application based on their social performance in their life cycle. This paper has some contribution to methodology as it proposes new methods and tools for conducting different phases of S-LCA.

3 Methodology

The general methodology is based on UNEP/SETAC "guidelines for social life-cycle assessment of products" and includes four main phases: goal and scope definition, life cycle inventory analysis, life cycle impact assessment, and life cycle interpretation. Figure 1 illustrates the assessment framework suggested for S-LCA by UNEP/SETAC (Benoît and Mazijn 2009). Social and socioeconomic aspects assessed in S-LCA are those that may directly affect company's stakeholders positively or negatively during the life cycle of a product. The subcategories are socially significant themes or attributes which include human rights, work conditions, cultural heritage, poverty, disease, and political conflict. Subcategories are classified according to stakeholder and impact categories and are assessed by the use of inventory indicators (Fig. 1).

Several inventory indicators and units of measurement/reporting types may be used to assess each of the subcategories. Each inventory indicator specifically defines the data to be collected; in the proposed methodology, our definition of assessment parameters, i.e., stakeholder categories, impact categories, subcategories, and inventory indicators, is based on UNEP/SETAC (2010).

Specific parts that authors have been added to the general methodology are novel methods and tools for conducting inventory analysis and impact assessment phases of S-LCA to adjust the framework for materials (and products) comparison purpose. In life cycle inventory analysis phase, a hot spot assessment is carried out using material flow analysis (MFA) and stakeholder and experts′ interviews .Based on the results of that, a pairwise comparison method is proposed for life cycle impact assessment applying analytic hierarchy process (AHP). To the best of authors' knowledge, it is the first time that this combination of powerful quantitative and qualitative tools is used in S-LCA. Table 2 summarizes general and specific features of the proposed methodology.

In the following, we present details of proposed comparative S-LCA. Discussion is organized based on the stages of "Technical Framework for Social Life-Cycle Assessment" presented in UNEP/SETAC guideline.
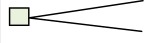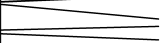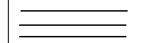
3.1 Definition of goal and scope
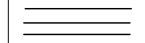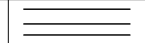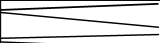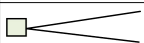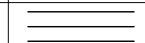
3.1.1 Goal of the study

The primary goal of S-LCA as developed in this paper is to assess and compare socio-economic impacts of different materials in their life cycle. Although the authors' focus is on material selection, the proposed methodology can be used for comparative assessment of products in general. This is because we have life cycle perspective and almost all materials are the subject of transformation into products in their life cycle. For example, the case study of this paper is two building materials: cement and steel. These are not materials only. In their life cycle, they are transformed into several products. Cement is transformed to concrete and concrete products, and steel is transformed to construction steel products. So, the main goal of this paper is to develop a methodology for comparative S-LCA in general. Second goal is the development of an assessment method for social impacts, which is suitable also for qualitative data and can be conducted easily. The impact assessment method should enable the identification of social hot spots in material life cycles as the UNEP/SETAC approach suggests many different and divers subcategories and indicators. The proposed approach aims not only to identify the best socially sustainable alternative but to reveal product/process improvement potentials to facilitate companies to act socially compatible.

Table 1 Classification of literature in S-LCA (focus on case studies)

Reference	Contribution to methodology	Literature review	Case study/applications			
			Simple	Comparative study		
			One product/material in one place	One product/material in more than one place	More than one product/material in one place	More than one product/material in more than one place
O'Brien et al. (1996), Schmidt et al. (2004), Dreyer et al. (2006), Dreyer (2009), Norris (2006), Weidema (2006), Reitinger et al. (2011), Jørgensen et al. (2009a, b, 2010), Hauschild et al. (2008)	✓					
Jørgensen et al. (2008), Benoit and Niederman (2010)		✓				
Ekener-Petersen and Finnveden (2013)				A laptop in several countries		
Chen and Kruijssen (2010)		✓		Fish species in Bangladesh, China, Thailand, and Vietnam		
Dreyer et al. (2010a, b)	✓					
Franze and Ciroth (2011)				Cut roses in Ecuador and Netherland		
Blom and Solmar (2009)					Three bio-fuels in Sweden	
Dobón López et al. (2009)			Plastic family materials in EU countries			
Gauthier (2005)			Charger for mobile phone batteries in France			
Kruse et al. (2009)	✓		Salmon production system			
Hunkeler (2006)	✓					Two detergents in seven country
Manhart (2007)			Chinese electronics industry			
Manhart and Grießhammer (2006)			A notebook in china			
Matos and Hall (2007)				Oil and gas; agricultural biotechnology		
Lagarde and Macombe (2013)	✓		Pig production in Croatia			
This work	✓				Two building materials in Iran	

Fig. 1 Assessment system in S-LCA (adapted from Benoît and Mazijn 2009)

Impact Categories	Stakeholder Categories	Subcategories	Inventory Indicators	Inventory data
Human rights	Workers			
Working conditions	Local Community			
Health and safety	Society			
Cultural heritage	Consumers			
Governance	Value chain actors			
Socio-Economic repercussions				

3.1.2 Scope of the study

To have information on the geographic location of unit processes is highly desirable if not necessary in S-LCA. Hotspots can be evaluated generically at the level of the country, but for case-specific S-LCA, more precise geographic information is needed.

3.1.3 Function and functional unit

According to UNEP/SETAC guideline, it is still necessary to define the functional unit, as well as the product utility (function), in the goal and scope phase of the study, as this provides the necessary basis for the product system modeling. More discussion about such necessity in the case study of this paper will come in Section 4.1 under the title "Function and functional unit." However, in both E-LCA and S-LCA, the impacts will generally not be expressed by functional unit (FU), if semi-quantitative or qualitative data are used. S-LCA often works with information about the attributes or characteristics of processes and/or their owning companies, which cannot be expressed per unit of process output. Such information is therefore not summarized per FU, either, when

Table 2 General methodology in this study and specific features developed by authors

Phase of the study	Stage of the phase	General methodology (UNEP/SETAC Guideline and methodological sheets)	Specific methods proposed by authors
Goal and scope definition	Goal of the study	The ultimate objective for conducting an S-LCA is to promote improvement of social conditions and of the overall socio-economic performance of a product throughout its life cycle for all of its stakeholders	In addition to the general goal, the specific goal is to assess and compare socio-economic impacts of different materials (and products in general) in their life cycle. (Comparative S-LCA)
	Functional unit	It is necessary to define the functional unit, as well as the product utility (function), as this provides the necessary basis for the product system modeling. However when using qualitative indicators and data in S-LCA, it may be difficult to link the results specifically to the functional unit.	Defining function and functional unit is needed to model product system. However due to the special type of characterization model in this method (AHP pairwise comparison), results cannot be related to functional unit.
Life cycle inventory analysis	Hot spot assessment	Social hotspots are unit processes located in a region where a situation occurs that may be considered a problem, a risk or an opportunity, in relation to a social theme of interest.	Material flow analysis (MFA) and stakeholder and experts' interviews are used for hot spot assessment.
Life cycle impact assessment	Characterization	The characterization models are the formalized and—not always— "mathematical" operationalization of the social and socio-economic impact mechanisms. They may be a basic aggregation step, bringing text or qualitative inventory information together into a single summary, or summing up quantitative social and socio-economic inventory data within a category.	AHP pairwise comparison is used for translating inventory results to impacts in a comparative way. The result is the relative preference of alternatives in each subcategory.
Life cycle interpretation	Interpretation	Identification of the significant issues; evaluation of the study conclusions, recommendations, and reporting	–

aggregating information across the life cycle in an S-LCA. As stated by Kruse et al. (2009), there are many socioeconomic indicators that cannot directly be related to the FU even if they can be measured quantitatively. They refer to these indicators as "descriptive indicators." For example, the indicator "living wage" in the stakeholder category of "workers" can be measured quantitatively as a dollar value, but it cannot directly be related to the functional unit. In contrast, they refer to "additive indicators" that can be measured quantitatively and related to FU. As an example, for subcategory of "health and safety" in stakeholder category of "workers," there is an additive indicator named number/percentage of injuries or fatal accidents in the organization by occupation.

Another factor that determines whether the results of S-LCA can be related to FU is impact assessment method. Even if additive indicators are measured per FU in inventory analysis phase of S-LCA, it may be impossible to relate the impact assessment results to FU due to characterization model. As stated by UNEP/SETAC guideline, there is an important nuance between the E-LCA and S-LCA characterization models. In E-LCA, the characterization model is an objective multiplication between the inventory data and a characterization factor defined in accordance with environmental sciences. When evaluating social information (either qualitative or quantitative), a scoring system may be used to help assess the "meaning" of the inventory data. This provides an estimation of the impact. So, in E-LCA it is straightforward to relate the impacts to FU, but in S-LCA it is not so.

Most of the characterization models in S-LCA developed to this time is not capable of relating impact assessment result to FU. For example, in Franze and Ciroth (2011), FU is "a bouquet of roses with 20 caulis per spray" and input–output tables were provided based on this FU in inventory phase, but in impact assessment phase, the results have not been linked to FU. They applied a scoring system which scores the indicators into five color-coded categories. In Blom and Solmar (2009), FU is "the amount of fuel used for driving a medium sized car 100 km." They applied a scoring system where subcategories are scored (1, 0, −1) and scores are then summed over the impact categories. Many additive indicators have been measured per FU in inventory analysis phase, but again, the impact assessment results have not been related to FU. The same thing can be said about work by Dreyer et al. (2010b), Ekener-Petersen and Finnveden (2013), and Chen and Kruijssen (2010). Characterization model in the proposed method in this paper is based on AHP pairwise comparisons. It is a type of scoring system that translates the inventory results to impacts in a comparative way. The result is the relative preference of alternatives in each subcategory. Thus, in the authors' proposed approach, results cannot be related to functional unit.

According to above discussion, is defining FU necessary? The answer is "yes." One should define FU not only for modeling product system but for gathering additive inventory data on the basis of FU. This is necessary for impact assessment. For example, an absolute measure for additive indicator "number/ percentage of occupational accident" in subcategory of "workers health and safety" may not indicate the real impact of the considered process on worker's health and safety, but a "per FU measure" may do that. It is the case especially when characterization models involve the use of "performance reference points." Performance reference points may be internationally set thresholds, or goals or objectives according to conventions and best practices. An absolute measure is not suitable for comparison with performance reference points and deciding about the size of impact. Furthermore, "per FU measures" are necessary particularly when comparison of two or more products is to be performed.

3.1.4 System boundaries

In S-LCA, it has been noted that for supporting management decisions it should be sufficient to include only those parts of the life cycle which can be directly influenced by the company. For example, the focus of Dreyer et al. (2006) is on the application of S-LCA in business decision making, and they narrow their focus on those parts of the life cycle that the companies can influence directly. This, however, cannot be applied to the use phase of a product as the social impact from this stage will be derived from the use of the product itself, rather than from the company's conduct. However, authors of this paper propose to include all stages of life cycle in hot spot analysis and inclusion of stages for a site specific survey should depend on the outcomes of the hot spot analysis.

3.2 Life cycle inventory analysis

3.2.1 General

The development of social indicators that can be integrated into LCA depends on the sector that is monitored and the national context. The UNEP/SETAC initiative is in the process of developing methodological sheets for 31 subcategories of impact of which the draft version is presently available for consultation (UNEP/SETAC 2010). For the analysis of a product system, it is important to define which indicators need to be assessed. In the proposed approach in this paper, both types of indicators, additive and descriptive, can be used. If the definition of assessment parameters, i.e., category indicators, impact categories, and damage categories, is according to international agreements and the best practices at the international level, the approach of S-LCA is a top–down approach with general indicators. This ensures an inclusion of those impacts which are relevant from a societal point of view. Like Dreyer et al. (2006), it is possible to add an optional layer to this framework to consider assessment parameters which are

specific to the product or sector of industry and to the company itself (specific indicators). S-LCA data may take several forms, depending on the goals of the assessment. Data may be quantitative, semi-quantitative (yes/no or rating scale responses), or qualitative (descriptive text). Methodological sheets developed by UNEP/SETAC initiative contain tables with suggested inventory indicators (metrics) for both generic and specific analysis. The tables also note whether data are available in quantitative, semi-quantitative, and/or qualitative form and provide data sources for each indicator.

In E-LCA, the origins of environmental impacts are processes as there is a natural link between the physical input and output of a process and a change in the quality of the environment. Social LCA is about impacts on people, and therefore, the focus must be on those activities which affect people in a product's life cycle. Dreyer et al. (2006) argued that social impacts on people in the life cycle of a product will depend on the conduct of the companies involved in the product chain and the way they organize and manage their business, rather than on the process itself, except for some direct occupational health impacts on workers. The authors therefore suggested that the conduct of a company towards stakeholders should be examined in the inventory analysis while the impact assessment phase addresses the impacts of this conduct on the stakeholders. This means that the social life cycle profile for a product is an aggregation of a number of individual company assessments of the actors in the product life cycle from raw material suppliers to retailers and end-of-life actors. Since the focus of this paper is on material selection, this common debate in S-LCA may be restated as this: whether material (and process) properties are the main driver of social impacts in a product chain or company's conduct? Although the claim asserted by Dreyer et al. (2006) may be clear, but real evidences may be helpful to understand the nature of social impacts and their origination. So, one of the goals of the case study in this research (as stated in Section 4.1) is to present such evidences.

3.2.2 Hot spot analysis (screening alternatives by general process data)

There is a need for prioritization in conducting an S-LCA because it is very costly, time consuming, and often not relevant to collect data on site at every organization involved in the production, use, and disposal of a good or a service. UNEP/SETAC guidelines suggest two approaches for prioritization: activity variables information (such as worker hours or value added) and social hotspots assessment. Activity variable information and social hotspots assessment results provide information that can guide the decision process concerning if and where to conduct case specific assessment. The use of activity variables provides a first set of information on the relative importance of the unit process. A hotspots

assessment provides additional information on where the issues of concern may be the most significant in the product's life cycle.

Currently, there is a global database that helps prioritization of unit processes in conducting an S-LCA called Social Hotspots Database (SHDB). According to Benoît et al. (2012), the two major components of the SHDB are the Social Theme Tables and Worker Hours Model. Social Theme Tables are country and sector-specific indicator tables to help identify hotspots, the countries and sectors of concern, in supply chains based on potential social impacts. Worker Hours Model uses a global input–output model derived from the Global Trade Analysis Project (GTAP) database and ranks Country Specific Sectors (CSS) within supply chains by labor intensity. In fact, Worker Hours Model provides activity variable information and Social Theme Tables are used for social hotspots assessment. Whereas the Social Theme Tables' results are available for 191 countries, the GTAP model enables the modeling of 113 countries and regions only. A Social Hotspot Index was calculated and used to help rank CSS and identify hotspots in the supply chain. SHDB faced three notable limitations: (1) a lack of granularity in the GTAP model; (2) unavailability of uncertainty and data quality indicators for the social issue data; and (3) limited published research on social impacts specific to countries and sectors. Beside these, SHDB needs more positive impacts, themes, and data. Positive impacts are not assessed with the Social Hotspot Index.

Regarding the above limitations of SHDB and in order to develop other helpful methods, in this paper a new approach is suggested to prioritize production activities for which site-specific data collection is most desirable. General material and process data in addition to expert judgment are used for carrying out hot spot analysis. An analysis will be conducted to identify hotspots that face socio-economic issues/impacts. The first step will be a screening to identify the important stages based on MFA. Subsequently, a few stakeholder and experts interviews are conducted to identify where the most pressing socio-economic issues are located. Therefore, the inclusion of stages for a site specific survey will depend on the outcomes of the screening and stakeholder interviews.

3.2.3 Material flow analysis

MFA, also known as substance flow analysis, is a well-established method to assess the sustainability of socioeconomic development and environmental change, particularly from the perspective of improving material/substance flow efficiency. Huang et al. (2012) stated that a material flow chart or accounting table makes sustainability assessment results comprehensive, comparable, and verifiable by (1) providing systematic information and indicators for sustainability assessment, (2) identifying critical pathways, links and key

substances in the anthroposphere, and (3) allowing the dynamic interaction between material flow and social, economic, and/or environmental processes to be analyzed. They propose that the role of MFA in sustainability assessment could be expanded by integrating MFA with other assessment methods. For example, Van der Voet et al. (2004) developed a method which combines aspects of MFA and LCA and attempted to add a set of environmental weights to the flows of the materials. Ma et al. (2007) stated that integrating MFA with risk estimation can facilitate examination of the risks from all human activities in a systematic way and provide a comprehensive understanding of risk generation and distribution corresponding to flows of substances in the anthroposphere and the environment. The systematic risk examination of material flows controlled by human activities makes sustainability assessment results more holistic and objective. However, the study of this field is only just beginning.

In this paper, authors propose use of MFA to screen life cycle of a product, identify the mainstream of material through its life cycle, and determine the most important stages of it. In the case of lack of data on activity variables such as worker hours and value added, this technique would be a valuable alternative. In fact, MFA is a visual, systematic, and more comprehensive demonstration of input–output tables that is a common tool in inventory analysis in many S-LCA studies (for example, Franze and Ciroth 2011). Input–output tables lack details on different stages of life cycle and do not help in identifying the mainstream of material through its life cycle.

Table 3 summarizes the main applications of MFA to social hot spot assessment providing some examples. Note that during data collection for MFA, many additional and supplemental data are gathered that are not depicted in MFA diagrams but are used for interpretation of MFA results to identify social hot spots, for example, level of automation in different processes in product life cycle, number of communities and companies involved in each stage of life cycle, employment rate, labor intensity, etc. Compared to SHDB Worker Hours Model that shows labor intensity, MFA basically shows material intensity in the supply chain. But using supplemental data can result in an approximation of labor intensity (as we will see in presented case study). However, as presented in Table 3, MFA provides further information to indentify social hot spots. It is worth noting that there is not an intention to use details of quantitative data collected for MFA for hot spot assessment. Instead, as presented more elaborately in Table 3, MFA leads us to identify trends of accumulation/depletion of stocks and to identify main streams in product life cycle that contribute to socio-ecological and socioeconomic impacts and consequently lead us to identify hot spots.

3.2.4 Stakeholder and experts interviews

The second step of data collection consists of a generic analysis that gives an overview of the social problems in the area (country, region) where the largest input to the life cycle of the product comes from. A few stakeholder and experts

Table 3 Main applications of MFA for hot spot assessment

Application	Example
To identify large and important flows of materials in the life cycle. For hot spot assessment, important flows are those involving more stakeholders (workers, local communities, society, consumers, and value chain actors) and are responsible for more socio-ecologic and socioeconomic impacts. This ensures that whether inclusion of a life cycle stage in further assessments is necessary or not.	Whether raw materials are imported from a region out of the system boundary or extracted and produced inside the system boundary? If the first is the case, for example it is not necessary to consider the extraction stage for stakeholder category of workers.
To determine whether reverse flows that close the loop are active or not. Lack of these flows or their weakness may indicate a hot spot (in terms of risky situations) in the life cycle. Existence of these flows also may indicate a hot spot in terms of occasional situations.	Is there any reuse, remanufacture or recycling flow?
To identify main environmental flows contributing to socio-ecological impacts.	Identifying flows contribute to resource depletion (this is related to subcategory of "access to material resource" in stakeholder category "local community")
	Identifying main emissions (contribute to safe and healthy living condition)
	Identifying waste streams (contribute to safe and healthy living condition)
	Identifying main energy flows—using material and energy flow analysis (MEFA)—(contribute to societal impacts)
To identify flows those are not related to function and functional unit and should be eliminated from assessment.	For example if the function of aluminum is to provide a building material, we should not include those flows of aluminum that relate to non-construction purpose (for example auto industry and home appliance).
To identify main stocks that may be responsible for socio-ecological or socioeconomic consequences.	For example, the stock of construction and demolition waste that are not recycled or disposed but abandoned in nature.

interviews are conducted to identify where the most pressing socio-economic issues are located. Based on the results of these interviews, it will be decided to which life cycle stages, stakeholders, subcategories, and inventory indicators should be included in next phase of S-LCA, i.e., life cycle impact assessment. Details on how to do such an analysis is provided in the section "case study."

3.3 Life cycle impact assessment

3.3.1 Site-specific analysis (rating and ranking alternatives by site-specific data)

Impact assessment and comparison of alternative materials needs using site specific data and general process data do not provide us with useful information for carrying out this phase of S-LCA. The main approach of this phase in proposed methodology is analytic hierarchy process (AHP). AHP is a multi-criteria decision-making tool that enables the user to establish weights for criteria and alternatives by means of a series of pairwise comparisons. Basically, the AHP helps in structuring the complexity, measurement, and synthesis of rankings. The AHP structures the problem as a hierarchy. To deal with a large and complex decision making problem, it is essential to break it down as a hierarchy. The AHP allows that. These features, coupled with its ease of implementation and understanding, make it suitable for the comparison of social

impacts of the material alternatives in their life cycle. More than that, it has proved to be a methodology capable of producing results that agree with perceptions and expectations that are critical in social assessment. The AHP also provides a methodology to allow the aggregation of individual judgments for taking group decisions. This is a good feature for social assessment where expert opinions play a critical role. Quantification is a major challenge in social assessment. AHP assists in converting decision-makers' intuition and gut feelings into numbers which can be openly questioned by others and can also be explained to others.

An important note is that AHP is capable of handling both types of indicators, namely additive and descriptive, through pairwise comparison. Additive indicators are quantitative, and descriptive ones may be quantitative or qualitative. AHP can handle both qualitative and quantitative measurements. Furthermore, one of the advantages of AHP is its capability to aggregate positive and negative effects. In AHP, pairwise comparison is used to translate positive and negative impacts of different alternative products into relative preferences. This mechanism transforms positive effects (that should be maximized) and negative effects (that should be minimized) into preference scores that should be maximized. This is a novel aggregation mechanism in impact assessment phase.

The first step in this approach is forming the hierarchy of decision making comprised of the goal, criteria, subcriteria, and alternatives (Fig. 2). This is almost equivalent to the
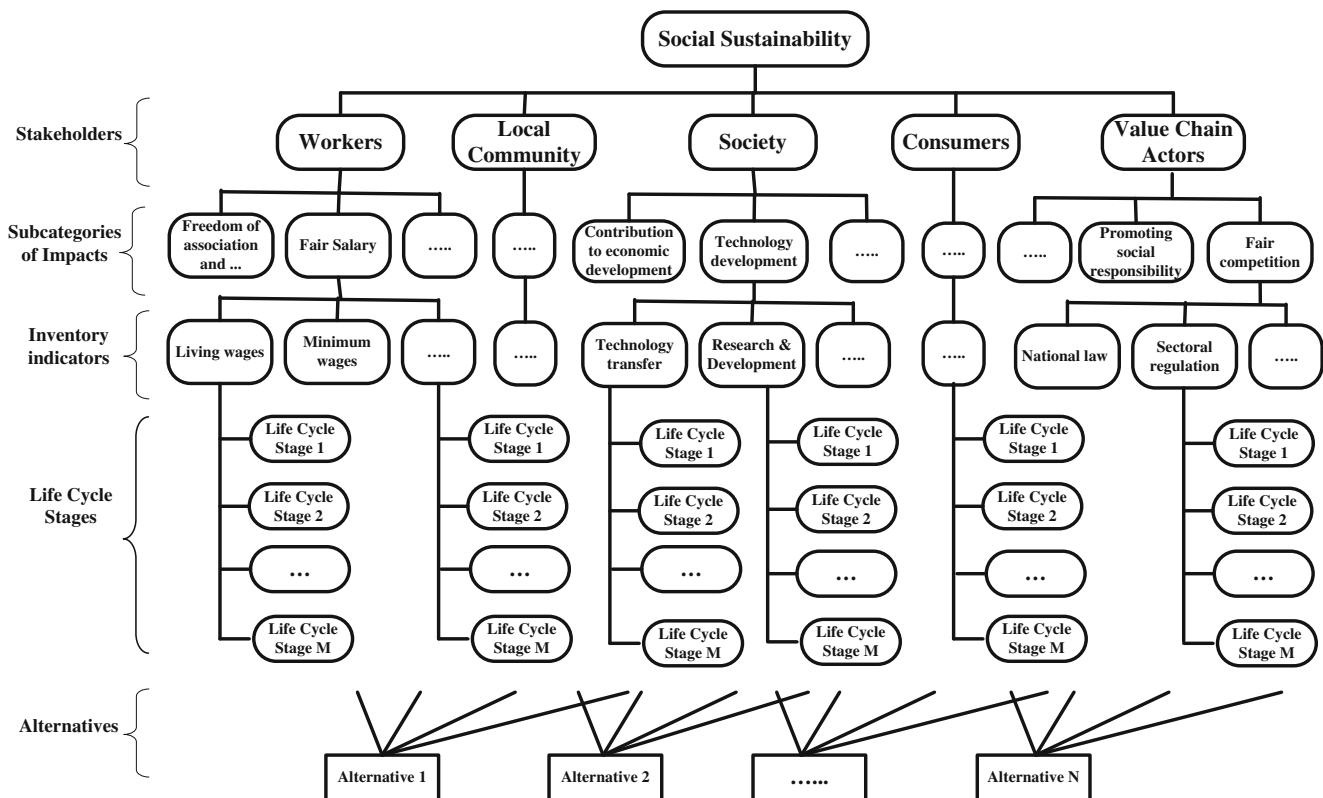

Fig. 2 Hierarchy of decision making in comparative S-LCA framework

stages of "selection of impact categories and subcategories" and "classification" in life cycle impact assessment phase of S-LCA. Stakeholders, subcategories of impacts, inventory indicators, and life cycle stages will be selected according to the result of hot spot analysis and classified in a hierarchical manner to form hierarchy of decision making. Figure 3 shows such a hierarchy.

The next step is characterization. The UNEP/SETAC guideline (2009) simply states that characterization will depend on the type of data available and may consist of summarizing qualitative data and summing up quantitative data. Here, it can also be helpful to use a scoring system to help assess the meaning of the inventory data. For characterization, the PROSA guidelines (Grießhammer et al. 2007) suggest using a grading scale of 1 to 10 (with 1 representing the best social situation) for a maximum of ten indicators per stakeholder group. As an analytical tool they propose SocioGrade, an Excel-based tool that calculates a numerical overall evaluation. Blom and Solmar (2009) and Franze and Ciroth (2011) also developed scoring systems previously described in the text.

Characterization method in our proposed methodology is based on AHP and is different from reviewed methods. It is based on a series of pairwise comparisons of elements in the hierarchy (life cycle phases and stages, stakeholders, subcategories, inventory indicators, and alternatives) and calculating relative weights of elements. Pairwise comparisons of each set of elements are performed subject to directly linked above element (parent) in the hierarchy. Next step is to conduct an inconsistency analysis to verify consistency of judgments in pairwise comparisons. According to Saaty and Vargas (2001), if the inconsistency ratio (IR) for one of pairwise comparison matrices is greater than 0.1, then revision is needed to perform on that matrix to improve consistency. After achieving an acceptable IR, next step can be started. It is the calculation of final scores of alternatives by hierarchical additive weighting (HAW) method that is the aggregation method in AHP. Based on these scores, alternatives can be ranked.

Final step in this phase is to perform a sensitivity analysis of results. This analysis determine the sensitivity of ranking to the value of relative weights of different elements such as life cycle phases and stages, stakeholders, subcategories, and inventory indicators.

Authors developed an Excel-based tool that considers scores of inventory indicators for the individual stages in the product life cycle. This tool provides a good foundation for demonstrating hierarchy of decision making in a tabular form, pairwise comparisons of elements in the hierarchy, calculating

Fig. 3 Steps of proposed methodology for comparative S-LCA
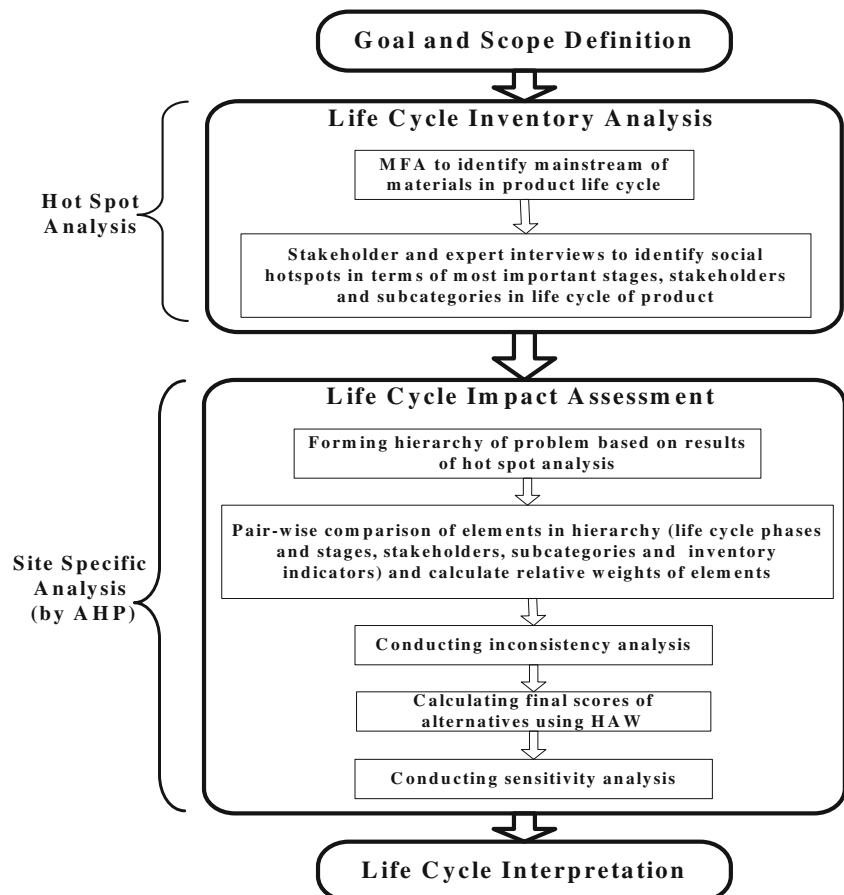
final scores, performing inconsistency analysis, and sensitivity analysis.

3.4 Life cycle interpretation

Life cycle interpretation is the process of assessing results in order to draw conclusions (Baumann and Tillman 2004). ISO 14044 (2006) defines three main steps:

1. Identification of the significant issues;
2. Evaluation of the study (which includes considerations of completeness and consistency);
3. Conclusions, recommendations and reporting.

For the first step, it is recommended to calculate aggregated scores for each impact category, subcategory, stakeholder category, and life cycle stage. Based on these aggregated scores, one may identify significant issues, key concerns, and where the issues of concern may be the most significant in the product's life cycle. It also enables identification of stakeholders that are the subject of key concerns. In the second step, the "completeness" aims to assess if all the relevant crucial issues have been addressed in the study and all necessary data collected. The two-stage approach presented in this paper for inventory and impact assessment, i.e., hot spot analysis and site specific analysis, provides a good basis for evaluation of completeness. The "consistency" aims to verify the appropriateness of modeling and of the methodological choices according to the defined goal and scope. Appropriateness of AHP for the comparison of social impacts of the material alternatives in their life cycle have been discussed in the previous section. Appropriateness of the other methodological choices in each case should be discussed in this phase. In the third step, conclusions may be about the final ranking of the alternatives regarding all considerations. Recommendations are a means to formulate options for actions and may be about future public and private policies regarding key stakeholders and key impact categories that identified in step 1 of current phase. Figure 3 shows steps of proposed methodology for comparative S-LCA.

4 Case study: S-LCA for selection of building materials in Iran

Manufacture, construction, and use of building and building materials make significant environmental, social, and economical impacts internally, locally, and globally. Selection of sustainable building material represents an important strategy in the design of a building. In the following, authors attempt to design an S-LCA for building material life cycle system in Iran. This is a generic model and more discussion will be needed to further refine the formulation of the subcategories and indicators.

Two main building structures, i.e., steel and concrete, are increasingly utilized in our modern buildings. It is difficult to figure out to which kind of the building structures is quantitatively socially preferable on the whole. Compared to concrete-construction building, the steel-construction building has many apparent advantages, such as saving water under dry construction condition, making less noise and dust, and destroying less land resource. Also, the steel-construction building is more propitious to protect environment for it produces less solid rubbish and is prone to recycle in end-of-life phase. Furthermore, the concrete is assumed to be one-off due to its significantly low recovery rate, whereas the recovery rate of steel is very high.

A few studies have been published to date on the LCA comparison of steel and concrete as construction materials. Xing et al. (2008) showed lower energy consumption and environmental emissions will be achieved by the concrete-framed building compared with the steel-framed building on the whole life cycle of building. The recycling potential of steel and the ability to be reused are two of the most important features of steel structures. The main result of the research by Passer et al. (2007) was that the three construction material, reinforced concrete, steel and timber are very close to each other, and no construction technique is preferable only on the basis of the environmental life cycle assessment. It is necessary to extend the one-dimensional environmental assessment by adding the two other pillars of sustainability. Based on author's literature review presented in Section 2, to date no attempt has been made to S-LCA comparison of steel and concrete as building materials. This study made such an attempt.

4.1 Goal and scope of the study

4.1.1 Goal of the study

The goal of this case study is to perform a comparative assessment of the social and socio-economic impacts in life cycle of concrete and steel as building materials in Iran in order to identify the best socially sustainable options. Concrete and steel cause negative impacts on society and environment. On the other side, provided jobs reduce unemployment and paid wages can promote the economic situation at the production sites. Hence, a second goal for the case study is to investigate trade-offs and possibly conflicting effects of these building materials in Iran and discovering product/process improvement potentials in the life cycle of them. The third goal of this case study is to answer the question as to whether the properties of these building materials are the main driver of social impacts in their life cycle or the conduct of companies involved in their chain.

4.1.2 Scope of the study

For hot spot analysis, geographical scope of this study is the entire of Islamic Republic of Iran. For site specific analysis, geographical scope is limited to the northern regions of Iran including three provinces named Golestan, Mazanderan, and Gilan.

4.1.3 Function and functional unit

The purpose of building in this study is to provide dwelling and working place for human. As stated in ISO 14044 (2006): "The scope shall clearly specify the functions (performance characteristics) of the system being studied." In agreement to this ISO statement, authors believe defining function is necessary for product system modeling. Here, authors defined the function of the two materials as providing a building material to create dwelling and working place for human. Following this definition, in the next stage, determining system boundary, we should consider only those parts of the two materials' life cycle that contribute to this function. For example we should not include those flows of iron/steel that relate to non-construction purpose (for example auto industry and home appliance). Thus, although non-construction flows are depicted in MFA results presented in Figs. 5 and 6 (because of mass conservation principle), they are out of system boundary (Fig. 4) and are not parts of the studied product system. Also for this study, the focus is on residential and non-residential buildings, which excludes mining and engineering construction (e.g., roads, bridges, tunnels). Residential covers building and alterations to private and public houses and units. Non-residential includes hotels, offices, shopping centers, education and health facilities, and factory buildings.

The functional unit used for this study will be the amount of material (concrete and steel) needed for 1 m^2 of floor area. Since this quantity is case specific and basically depends on the type of building (residential and non-residential) and its geometry and structural properties, for the purpose of demonstrating the proposed methodology we will consider a hypothetical building. The hypothetical building in this research needs 0.8 t concrete (and as a result, approximately 0.1 t cement) and 0.1 t steel per 1 m^2 floor area. The building's assumed life span is 50 years, and for the sake of simplicity, it is assumed to be the same for the two materials. However, as we will see in the next section, since the use and maintenance stages of life cycle will be eliminated from site-specific assessment, this life span has no implications for site-specific inventory analysis.

4.1.4 System boundaries

Figure 4 represents the generic life cycle framework of a building material covering the important phases and stages. A building material's life cycle can be organized into three phases: pre-building, building, and post-building. These phases parallel the life cycle phases of the building itself and relate to the flow of materials through the life of a building. Pre-building phase describes the production and delivery process of a material up to, but not including, the point of construction. This includes discovering raw materials in nature as well as extracting, manufacturing, packaging, and transportation to a construction site. This phase has a great potential for causing environmental and social damage. Understanding the environmental and social impacts in the pre-building phase will lead to the wise selection of building materials. The building phase refers to a building material's useful life. This phase begins at the point of the material's
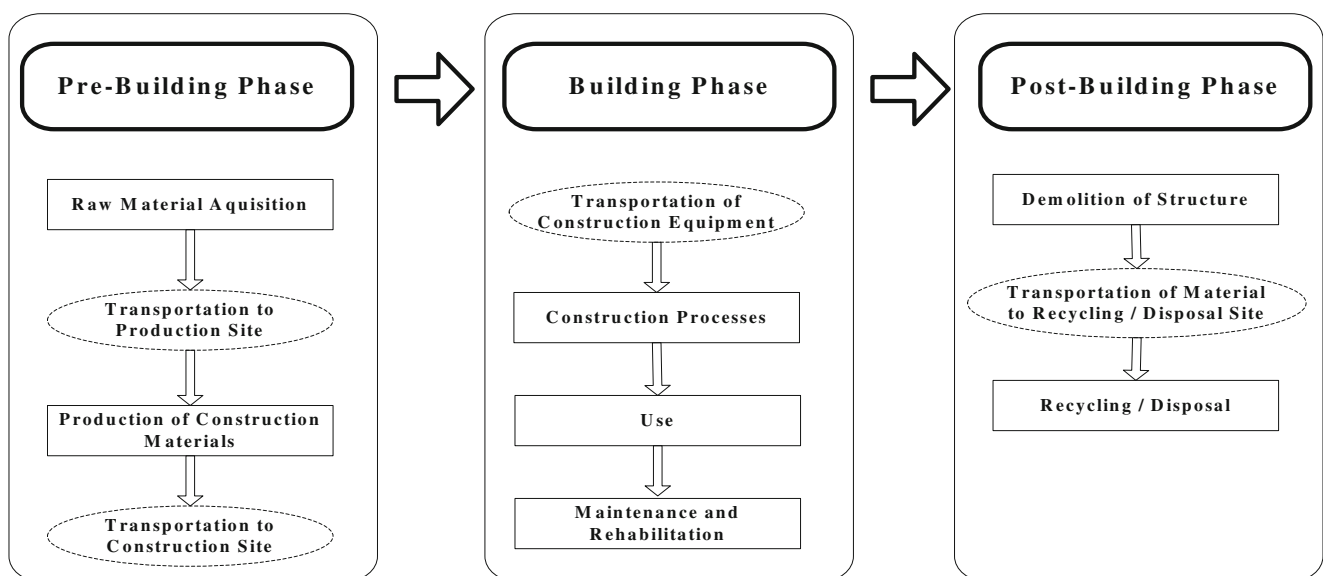

Fig. 4 Generic life cycle of a building material used for hot spot analysis

assembly into a structure, including maintenance and repair of the material, and extends throughout the life of the material within or as a part of the building. The post-building phase refers to a building material's end of life that includes demolition of structure and recycling/disposal options.

This general framework is used as system boundary for hot spot analysis in life cycle inventory phase of this case study. The inclusion of stages for a site specific survey will depend on the outcomes of the hot spot analysis. Thus, the system boundary will be modified for the life cycle impact assessment phase.

4.2 Life cycle inventory analysis: hot spot analysis

4.2.1 General

Inventory indicators In this case study, our definition of assessment parameters, i.e., stakeholder categories, subcategories, and inventory indicators is based on UNEP/SETAC (2010). Thus, the approach of S-LCA in this case is a top–down approach. In methodological sheets developed for 31 subcategories by UNEP/SETAC initiative, both types of additive and descriptive indicators are suggested. Here, both additive (for example number of occupational accidents) and descriptive (for example living wage) inventory indicators are used for assessment.

Data collection Under the life cycle inventory, data of the national level have been gathered through a desktop screening, searching for information on the Internet, in literature, journals, and national statistics (for example, Iran MIM (2012); IMIDRO (2012); Iranian cement portal (2012); Iran steel industry statistics (2012); Iran steel statistics (2012)). A number of interviews were also performed with producers, importers, and interest organizations in order to receive a more in-depth knowledge of the issues. Since this assessment is a hotspot assessment, mostly generic data have been used. A substantial amount of data about the key social issues has been collected.

4.2.2 Results

Material flow analysis The hot spot analysis presented here is based on a synthesis of production and market data provided by the individual companies for the purpose of this study. Current Iranian steel and concrete life cycle data are not extensive. Informed judgment was needed to fill gaps in the data. Despite the above limitations, the data used in this study are considered the most comprehensive cradle to grave data, and they should be a very useful input for modeling of the materials flows. Although some data are approximate, for the purpose of hot spot analysis this does not make any problem.

Figures 5 and 6 demonstrate the overall flow of cement / concrete and iron/steel in the Iran economy for 2012. All of the stocks and flows data are depicted in the diagrams, and

here, we only discuss the implications of this data for social hot spot analysis. Table 4 explains the main applications of MFA to social hot spot assessment in the case study. From the third column, authors can conclude that from a socio-ecologic and socioeconomic point of view the following four stages are more important than others: extraction of raw materials, production of construction materials, construction, and end of life. So, these stages are recognized as being social hot spots in the life cycle of cement and steel. However, the final choice will be made after analyzing stakeholder and experts' interviews.

Stakeholder and experts interviews A few stakeholder and experts interviews were conducted to identify the most pressing socio-economic issues and where these issues are located. Table A1 (see Electronic supplementary material) shows the structure of data collection via interviews with stakeholders and experts in hot spot analysis. It shows the characteristics of interviewees and the information provided for them. Using the provided information and their knowledge, interviewees scored the inventory indicators at each life cycle stage (each cell in Fig. 7) based on scoring system presented in Fig. 8. The color scheme is simple to apply and easy to understand. Each color is corresponding to a numerical score in order to be able to average the scores of all interviewees and summarize them.

The results of these interviews are summarized and aggregated in the tabular form of the problem hierarchy (Fig. 7). All stakeholder categories as suggested in the UNEP/SETAC guideline were included, i.e., workers/employees, local community, society (national), consumer (covering end-consumers only), and value chain actors. Based on UNEP/SETAC guidelines and using experts' opinions, a subset of subcategories and inventory indicators selected that serve as a generic list to be considered and applied for the life cycle. Only those subcategories that have a sensible impact in this special case have been taken into account. So, irrelevant or less important subcategories are ignored. However, this is just a case study and does not affect the general procedure. In any case, relevant and important subcategories (may be all of them) should be selected. This is a preliminary filtration on subcategories and inventory indicators. Subcategories as identified for each stakeholder group may not be relevant for all stages in the life cycle and may be dropped from the analysis.

The scoring sheet presented in Fig. 7 can be used to quickly identify social issues that need attention. Considering large positive and large negative impacts in the scoring sheet, a subset of elements of this sheet will be selected as input to the next phase of study, i.e., life cycle impact assessment. Cells with large positive impacts indicate a social hot spot in terms of occasional situations. Cells with large negative impacts indicate a social hot spot in terms of risky situations. Cells with lightly negative impacts or indifferent effects may be dropped from further analysis. A simple look at Fig. 7 reveals
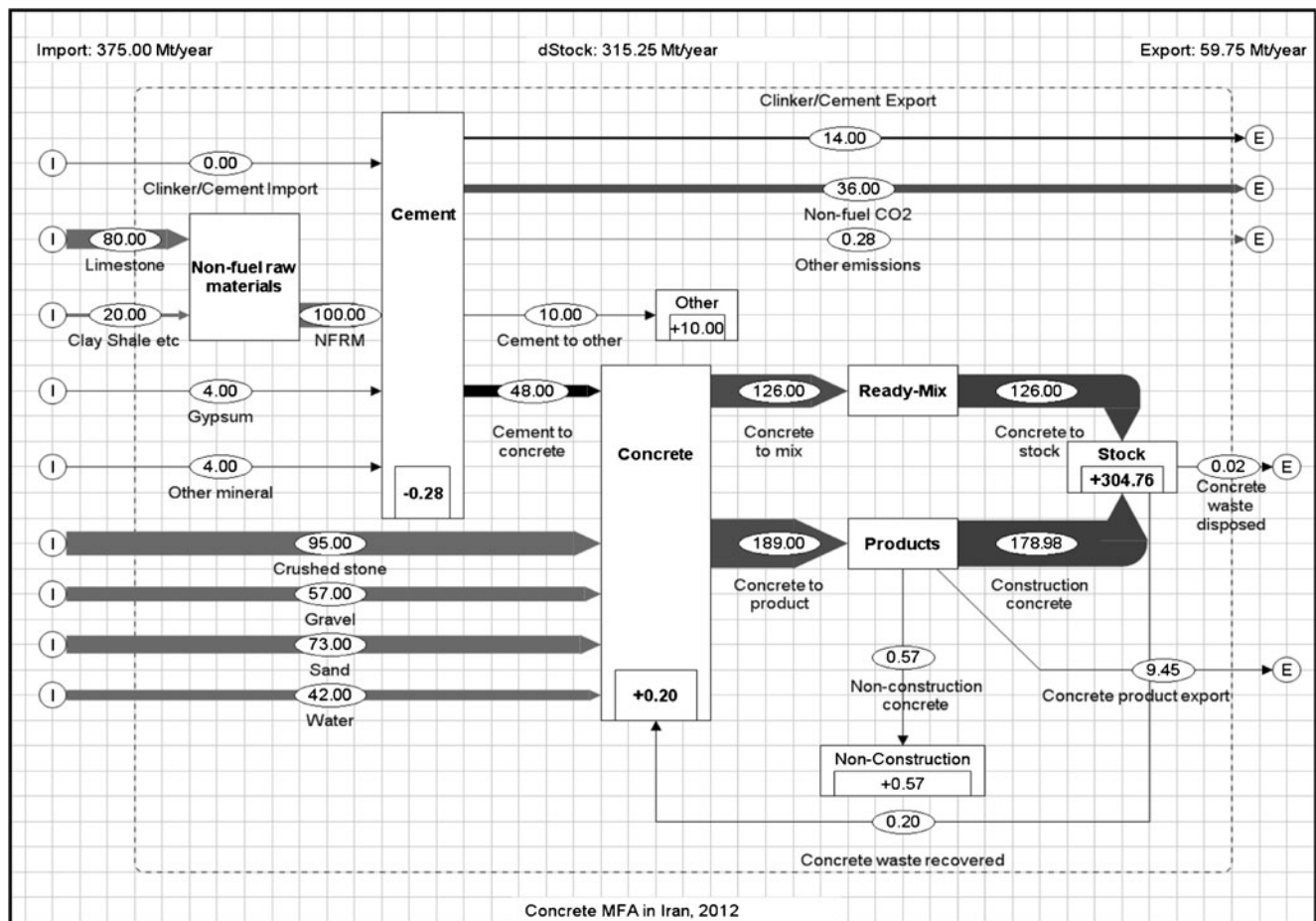
Fig. 5 MFA of cement/concrete in the Iran economy for 2012. All units are million metric tons (Mt). The model of flows excludes clinker production, fuel consumption, and CO_2 from the combustion of fuel

the importance of workers, local community, and society as main affected stakeholders and extraction, production, construction, and disposal as hot spots in life cycle of the two building materials. Based on these results, a subset of elements of this sheet will be selected as input to the next phase of study, i.e., life cycle impact assessment.

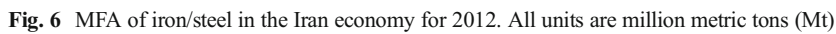4.3 Life cycle impact assessment: site-specific analysis

4.3.1 General

Case introduction For site specific analysis, northern region of Iran is selected. A cement manufacturing company, Peyvand Golestan (PG cement), and a steel manufacturing firm, Ferro Gilan complex (FG complex), are selected for company-level data collection. Similarity between ecological and social environment of these two firms make them suitable for the purpose of comparison. For stakeholder category of "workers" in pre-building phase, the needed data are mainly collected from the above two companies and in other phases data are collected from any related companies in the region.

For stakeholder category of "local community," the needed are data collected from local communities in the region. For stakeholder category of "society," country-level data are used.

Data collection Data for this phase come from several sources: direct observation, studying company documents, interview with managers, staff and workers of the companies, and reading documentation such as articles from journals, newspapers, and web sites. These data will be used for pairwise comparisons in this phase and for interpretation in the next phase of the study.

Table A2 (see see Electronic supplementary material) shows a summary of site-specific life cycle inventory data for cement/concrete. These data were provided for experts when doing the pairwise comparisons. The fourth column shows the inventory indicator results for each life cycle stage. Some of the indicators are additive and presented "per FU" and some of them are descriptive (quantitative or qualitative) and not presented "per FU." Some inventory data were not found, and some indicators are not applicable for certain stages. The last column shows the source of data. Similarly,

Fig. 6 MFA of iron/steel in the Iran economy for 2012. All units are million metric tons (Mt)

Table A3 (see see Electronic supplementary material) shows a summary of inventory data for iron/steel. Using these inventory data and their knowledge, experts will make pairwise comparisons.

Analysis method In S-LCA, it will be challenging to arrive at an objective assessment of the magnitude of the social issues and their impacts as different stakeholders, communities, or countries may perceive impact differently. AHP is a suitable tool for objective assessment of subjective issues and hence is used in this phase for life cycle impact assessment and comparison of the two alternative materials. An important consideration to note is that this system is based on a high level of individual interpretation. The proposed method considers among potential impacts also real impacts. In the following, five steps of the method are described as applied for the above cases.

4.3.2 Steps

Step 1   Forming the problem hierarchy
          Figure 9 shows the selected elements of the problem hierarchy for site specific analysis based on the results of hot spot analysis and using experts' judgments. Three stakeholder categories—workers, local community, and society—were chosen as main affected stakeholders and four life cycle stages—

extraction, production, construction, and disposal—were preferred as hot spots in the life cycle. In addition, a subset of subcategories and inventory indicators were recognized and picked as most positively or negatively affected ones in the life cycle. These elements are the subject of pairwise comparisons.

Step 2   Pairwise comparisons
          Pairwise comparison of elements in the problem hierarchy is performed to establish relative weights to aggregate the S-LCA subcategories into a single index. Table 5 shows the scoring system for pairwise comparison of elements in the hierarchy. Each number in the scoring system reflects the degree of importance (preference) of one element relative to the other. Ninety pairwise comparison matrices should be completed in order to be able to calculate final score of each alternative: 1 matrix for stages of pre-building phase, 1 matrix for phases of the life cycle, 1 matrix for comparison of three stakeholders, 3 matrices for subcategories of each stakeholder, 4 matrices for inventory indicators of subcategories (those with more than one indicator), and 80 matrices for pairwise comparison of the two alternatives for each cell in Fig. 9 (intersection of inventory indicators and life cycle stages).
          Each pairwise comparison matrix is aggregated from individual matrices of a group of 20 experts.

Table 4 Main applications of MFA for hot spot assessment in the case study

Type of application	Evidence from MFA diagrams	Implications for social hot spots in the case (using evidence from MFA plus supplemental data)
To identify large and important flows of materials in the life cycle.	Main raw materials needed for production of steel and cement are extracted from mines inside the country. There are large flows of limestone for cement production; crushed stone, gravel, sand and water for concrete production; and iron ore and coal for steel production. (Note that all import flows from outside the country explicitly stated in Figs. 6 and 7. For example, steel scrap import)	Due to low level of automation, a large number of labors are involved in extraction of mentioned raw materials and production of the construction materials directly and indirectly. For example, there are almost 5,000 direct labors and 3,500 direct/indirect labors per million tons steel and cement production in Iran, respectively. Currently, there are 68 cement production firms and 15 steel production firms in various regions of Iran. Thus several local communities are affected by these two processes, i.e., extraction and production. Steel and concrete in buildings represent a significant impact on employment and economy, particularly in the main steel making and cement making regions. So, there is a great potential for social impacts on workers and local communities in these two stages of life cycle.
To determine whether reverse flows that close the loop are active or not.	There are recycling flows both for concrete and steel in end of life. In year 2012, 1.2 million tons steel scrap (including scrap from buildings and other steel containing goods) was recycled. Also 0.2 million tons concrete waste was recovered.	Iranian overall steel recovery rate at end of life is calculated to be above 70 %. However, for steel building materials, the figure is almost 85 %. This figure is moderately good and can be improved. Hence, it may indicate a hot spot in terms of occasional situations in steel end of life.
		In contrast, there is no concrete recycling system in Iran at all. Furthermore, the average life of produced concrete in Iran is notably lower the universal norms (estimated to be 10 years in Iran), and this leads to the short life of concrete structures and large flow of concrete waste in Iran. This picture may indicate a hot spot in terms of risky situations in concrete end of life.
To identify main environmental flows contributing to socio-ecological impacts.	Flows contribute to resource depletion: minerals such as limestone, crushed stone, gravel, sand, iron ore, coal; and water	Cement/concrete and steel production processes are responsible for large depletion of mineral and water resources in Iran.
	Main emissions: CO_2 and silica dust from cement production; CO_2 from steel production	Cement and steel production processes are responsible for a large emission of CO_2 in Iran. According to report of Iran's Department of Environment (2010), iron and steel production account for 43.4 % and cement production contribute to about 40.3 % of CO_2 emissions from industrial processes. There is a great potential for technology development (specially adopting green technologies) in the phases of extraction, production, and construction in Iran.
	Waste streams: concrete waste and steel scrap	Cement and steel production processes are hot spots in terms of socio-ecological impacts.
To identify flows those are not related to function and functional unit and should be eliminated from assessment.	Flows of steel and concrete that relate to non-construction purpose or construction of non-building structures	Since authors defined the function of the two materials (steel and cement) as providing a building material to create dwelling and working place for human, we should not include those flows of steel and concrete that relate to non-construction purpose or construction of non-building structures in next assessment phase (however, no distinction is made between construction of buildings and non-building structures in MFA diagrams due to lack of data)
To identify main stocks contributing to socio-ecological/socioeconomic consequences.	Stock of concrete and steel waste disposed during construction and demolition	Stock of concrete and steel waste disposed is small. However hibernating stocks (in-use stock of materials that has been put out of service but not

Table 4 (continued)

Type of application	Evidence from MFA diagrams	Implications for social hot spots in the case (using evidence from MFA plus supplemental data)
		discarded completely) may be large. There are not reliable statistics on their number and effects. There is further need for empirical research in this regard. No implications for hot spot in the case were found.
	Stock of in use concrete and steel in the consumption sector	

			Subcategory scores by life cycle stages						
Stakeholder Categories	**Subcategories**	**Inventory Indicators**	**Pre-Building Phase**		**Building Phase**			**Post-Building Phase**	
			Raw material acquisition	Production of construction material	Construction	Use	Maintenance & Rehabilitation	Demolition	Disposal / Recycle
Workers	Freedom of association and collective	Respect to freedom of association and collective bargaining							
	Health and safety	Occupational accidents							
	Fair salary	Living / non-poverty wages							
	Forced labor	Use of forced labor							
	Child labor	Use of child labor							
	Equal opportunity/ discrimination	Discrimination among different groups of gender, age, etc.							
Local Community	Access to material resources	Changes in land ownership/ land use							
		Levels of industrial water use							
		Extraction of material resources							
	Safe and healthy living conditions	Burden of disease							
		Pollution levels							
		Waste generation							
	Local employment	Job creation							
		Use of local labor							
		Use of technology that generate employment							
		Presence of local supply network							
	Local community acceptance	Presence of complaints by local community							
	Cultural heritage	Protection of cultural heritage							
Society	Technology development	Technology development							
		Technology transfer							
		Research and development							
	Contribution to economic development	Contribution of product to economic progress (GDP, revenue, wage level, unemployment, etc.)							
	Suppliers development	Use and support of national suppliers							
Consumers	Health and safety	Presence of consumer complaints							
		Indoor air quality (IAQ)							
Value chain actors	Fair competition	Monopoly and anti-competitive behavior							
	Supplier relationship	On time payment, sufficient lead time, etc.							

Fig. 7 The results of stakeholder and experts interviews for social hot spot analysis of concrete and steel

Fig. 8 Scoring scheme for social hot spot assessment

very negative effect	negative effect	lightly negative effect	Indifferent effect	positive effect	Subcategory is not present
9	7	5	3	1	0

In fact, to compensate this weak point that AHP is based on a high level of individual interpretation, group decision making is used. Experts were chosen in a way that their expertise covers all elements of the problem hierarchy as much as possible. Aggregation of the expert's opinions was made by geometric average method that is a well-known method for this purpose. Table 6 characterizes the experts who performed pairwise comparison and their or expertise.

Based on the pairwise comparisons matrix, the final weight for each element is calculated using a simple approximate method called "arithmetic average." According to this procedure, cell values in a pairwise comparisons matrix are divided by the column totals, the resulting values summed per row and divided by the dimension of matrix, resulting in the final weights of each element.

Step 3   Inconsistency analysis

Inconsistency is an inherent feature of any judgments in the form of pairwise comparison. Indeed, there may be inconsistency in pairwise comparison of more than two elements. In AHP, there is a rigorous procedure for calculating inconsistency of a pairwise comparison matrix and of a hierarchy as a whole.

Fig. 9 Selected elements of the problem hierarchy for site specific analysis based on the results of hot spot analysis

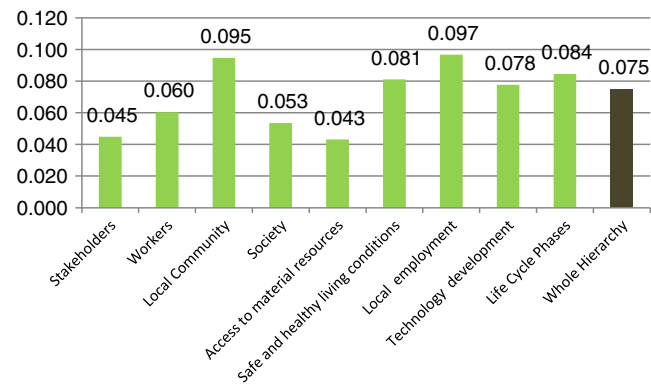| Stakeholder Categories	Subcategories	Inventory Indicators	Subcategory scores by life cycle stages			
			Pre-Building Phase		Building Phase	Post-Building Phase
			Raw material acquisition	Production of construction material	Construction	Disposal / Recycle
Workers	Freedom of association and collective	Respect to freedom of association and collective bargaining				
	Health and safety	Occupational accidents				
	Fair salary	Living / non-poverty wages				
Local Community	Access to material resources	Changes in land ownership/ land use				
		Levels of industrial water use				
		Extraction of material resources				
	Safe and healthy living conditions	Burden of disease				
		Pollution levels				
		Waste generation				
	Local employment	Job creation				
		Use of local labor				
		Use of technology that generates employment				
		Presence of local supply network				
	Local community acceptance	Presence of complaints by local community				
	Cultural heritage	Protection of cultural heritage				
Society	Technology development	Technology development				
		Technology transfer				
		Research and development				
	Contribution to economic development	Contribution of product to economic progress (GDP, revenue, wage level, unemployment, etc.)				
	Suppliers development	Use and support of national suppliers				

Table 5 Scoring scale for pairwise comparison

Verbal phrase	Indifferent	Low preference	Moderate preference	Strong preference	Very strong preference
Scores	1	3	5	7	9

Fig. 10 IR for each pairwise comparison matrix and whole hierarchy

Acceptable level of inconsistency depends on the decision maker's judgment. However, Saaty and Vargas (2001) suggest the level of 0.1 as acceptable level of inconsistency ratio (IR). Since each pairwise comparison matrix of two elements is consistent, all of 80 matrices for pairwise comparison of the two alternatives are consistent and their IRs are 0. Also, the matrix for pairwise comparison of stages of pre-building phase is consistent. Other matrices are inconsistent and their IRs are greater than zero. Figure 10 shows the IR for each pairwise comparison matrix and whole hierarchy in the present case study. As seen, all of IRs are lower than 0.1, and hence, no revision is necessary to be made on the judgments.

Step 4   Calculating final score and ranking

Figure 11 shows a screenshot of Excel-based model for life cycle impact assessment. Total scores of alternatives were calculated applying HAW procedure and demonstrated in Fig. 12. This aggregation of results clearly shows that the steel life cycle contains better social impacts and overall is preferred to concrete. The interpretations of the results of this aggregation will be discussed further in the interpretation phase. To divide the result into the different operations in life cycle is important in order to display as to which operations the most problems occur (Fig. 13). Second way to view the results is to distribute them according to the stakeholders (Fig. 14). Third way to present the results is to distribute them

according to the subcategories. This can provide an estimate on how the materials affect the different areas (Fig. 15).

Another way to view the results is to distribute them according to the impact categories. According to UNEP/SETAC guideline and based on authors search, for the time being, there are no characterization models between subcategories and impact categories that are generally accepted by S-LCA practitioners. Thus, actually there is no basis for linking subcategories and impact categories. Only there are some ideas from literature. Blom and Solmar (2009) and Franze and Ciroth (2011) suggested such linkage between subcategories and impact categories. However, their linkages are very different. The linkage matrix proposed in Franze and Ciroth (2011) is too much dense, i.e., each subcategory is linked to most of impact categories. In contrast in the work by Blom and Solmar (2009), each subcategory contributes to only one impact category. None of these works provide a basis for such linkage. Not even this paper provides such basis. It presents only an example of a scoring system aggregated into impact

Table 6 Experts who performed pairwise comparison and their expertise

Expert's organization	Number of experts	Role or expertise
Province-general office of industry, mine, and trade (Guilan, Mazanderan, and Golestan provinces)	3	Technical director
Province-general office of economic and finance affairs (Guilan, Mazanderan, and Golestan provinces)	3	Technical director
Regional office of department of environment (Guilan, Mazanderan, and Golestan provinces)	3	Technical director
Regional office of natural resources (Guilan, Mazanderan, and Golestan provinces)	3	Technical director
Regional waste management organization (Guilan, Mazanderan, and Golestan provinces)	3	Technical director
Golestan University	1	Civil engineering professor
Guilan University	1	Civil engineering professor
PG cement company	1	Chief Executive Officer
FG Guilan complex	1	Chief Executive Officer
Trade association of construction workers of northern region	1	Head of association

Fig. 11 Screenshot of Excel-based model for life cycle impact assessment

categories (Table 7). Due to the lack of cause–effect chains of social impacts, the connection between subcategories and impact categories bases on own thoughts (number 1 in cells). Considered impact categories are (1) health and safety, (2) socio-economic repercussions, (3) human rights, (4) cultural heritage, (5) governance, and (6) working conditions. Figure 16 shows the aggregated score for each impact category for further interpretation. Score of each impact category is simply calculated by averaging (applying equal weighting) scores of subcategories that have a connection with that impact category.

Step 5   Sensitivity analysis

Sensitivity analysis is an optional step in the proposed method. However, since the results are based on a personal judgment, sensitivity analysis can help
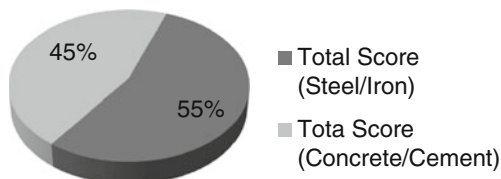
to improve interpretation. Generally, standard procedures for sensitivity analysis in AHP can be used to determine the sensitivity of results to different weights in the hierarchy. However, in this case study, a special tool is used for this purpose called "mixing triangle" or "ternary diagram" (Hofstetter et al. 1999). It is suitable wherever three criteria are considered. Since in the present hierarchy there are three stakeholders and three life cycle phases, this tool can be applied. Figures 17 and 18 show the result of sensitivity analysis for stakeholders and life cycle
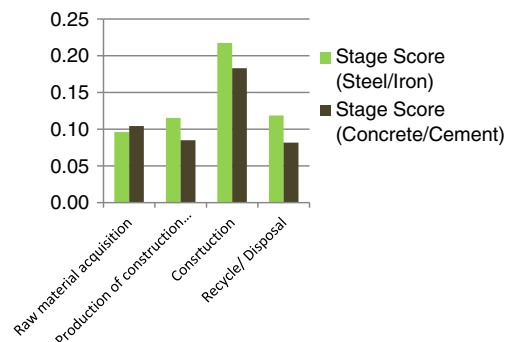

Fig. 12 Total score (preference) for each alternative

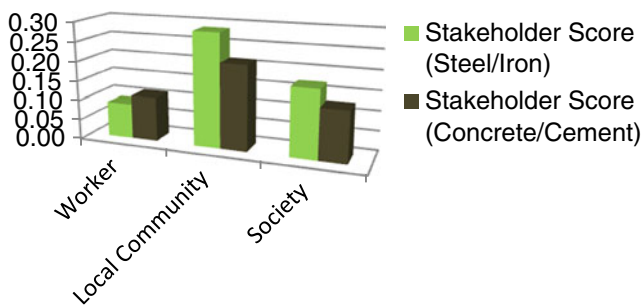**Fig. 13** Scores of life cycle stages for each alternative

Fig. 14 Scores of stakeholders for each alternative

phases, respectively. It shows dominance areas, i.e., combination of weights that make alternative A, preferable to alternative B, and vice versa.

4.4 Life cycle interpretation

4.4.1 Identification of the significant issues

Important social findings According to Fig. 13, steel has a sensible dominance over concrete in three stages in life cycle: production, construction, and end of life. However, in extraction stage, concrete is preferred. The reason may be perceived by looking at Figs. 14 and 15. Steel acquired less preference score in stakeholder category "workers" than concrete. This occurred mainly in extraction stage due to worse condition of steel in three subcategories of "freedom of association and collective bargaining," "worker's health and safety," and "fair salary". Figure 16 indicates that human rights and working conditions are the main social challenges of steel industry in the studied region. High level of working accident, low level of wages, and lack of job security in mining of coal in northern region of Iran are the most problematic issues in steel industry. Figure 18 implies that increasing the importance weight of stakeholder category "workers" can reverse the ranking of alternatives.
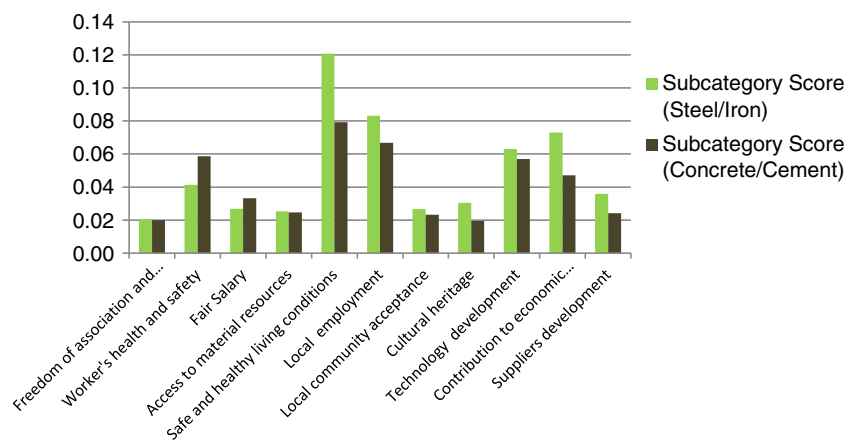
Against, social profile of concrete and cement industry is damaged mainly due to the negative impact of cement production on safe and healthy living condition. There are many complaints by peoples who live near the cement production sites. In fact, cement production obtained a lower score in the subcategory "local community acceptance" compared to steel production. High level of air and noise pollution and high level of resource depletion in extraction of limestone in the studied region are the most problematic socio-ecological issues in the life cycle of cement industry. Extraction of limestone is accompanied with horrible explosions that create noise pollution for local inhabitants. Damages to agriculture, herbal cover, and animal species are the other concerns of local communities. Creation and propagation of silica dust is one of the critical concerns of local inhabitant. One of the future options for improving social performance of cement industry is to reduce pollutions of cement production and to enhance the living condition of local communities. Another important issue in concrete industry is the subject of waste generation and management. The material waste generated on a building construction site can be considerable. The selection of building materials for reduced construction waste, and waste that can be recycled is critical for sustainability of construction projects. These include the reuse and recycling of waste from concrete manufacture such as water and unused returned concrete. Concrete from demolition can be crushed and recycled as aggregate. Reinforcing steel in concrete can be recycled and reused. Unfortunately, there is no systematic recycling of concrete in the studied region and this area is one of the best opportunities for future investment in concrete industry.

Critical methodological issues The unique feature of the proposed framework among similar frameworks in social LCA is its specialty to materials and products comparison due to its special characterization model, i.e., AHP pairwise comparison. As seen in Sections 3.2 and 3.3, this leads to considerable differences in methodological issues of S-LCA. Particularly

Fig. 15 Scores of subcategories for each alternative

Table 7 Scoring system aggregated into impact categories

Subcategories	Impact categories						Subcategory scores	
	Human rights	Working conditions	Health and safety	Cultural heritage	Socio-economic repercussions	Governance	Steel/iron score	Concrete/cement score
Respect to freedom of association …	1	1				1	0.020	0.020
Occupational accidents		1	1				0.044	0.056
Living/non-poverty wages	1	1					0.026	0.034
Changes in land ownership/land use				1	1		0.008	0.007
Levels of industrial water use					1		0.009	0.011
Extraction of material resources				1	1		0.007	0.008
Burden of disease			1		1		0.032	0.028
Pollution levels			1		1		0.051	0.029
Waste generations			1		1		0.037	0.023
Job creation					1		0.023	0.022
Use of local labor					1		0.024	0.021
Use of technology that generate employment					1		0.016	0.014
Presence of local supply network					1		0.014	0.016
Presence of complaints by local community						1	0.029	0.021
Protection of cultural heritage				1	1		0.031	0.020
Technology development					1		0.018	0.018
Technology transfer					1		0.018	0.018
Research and development					1		0.023	0.025
Contribution of product to economic progress (GDP, revenue, …)					1		0.068	0.052
Use and support of national suppliers					1		0.037	0.023

proposed impact assessment method is different from common S-LCA. In the other words, this research customized S-LCA for comparative studies. Expert opinions play an important role in the proposed framework; hot spot analysis and pairwise comparisons all will be conducted in light of expert judgments. Implementation is facing difficulties, especially due to a lack of specific data and a high level of need for individual interpretation.

From the above, it is clear that the proposed framework for applying S-LCA in comparative studies is novel and offers a generic, comprehensive, easy to understand, and convenient decision-making method that employs different tools and techniques in order to characterize the comparison task. The method lays emphasis on decision-making methodology and gives much attention to the issues of identifying the social hot spots and associating the alternatives with them. It enables a more critical assessment of social sustainability of alternative materials or products.

It will be challenging to arrive at an objective assessment of the magnitude of the social issues and their impacts as
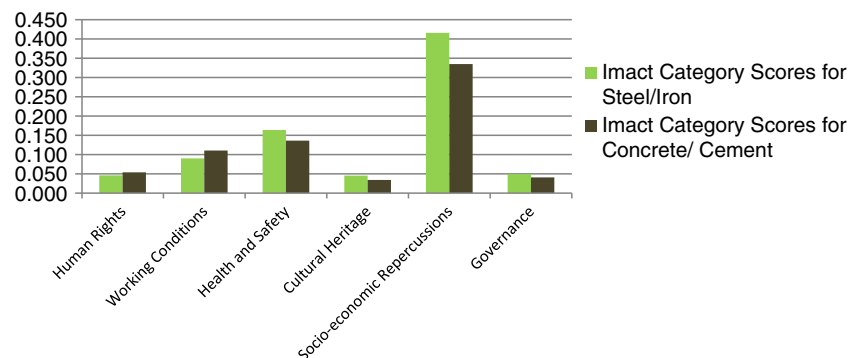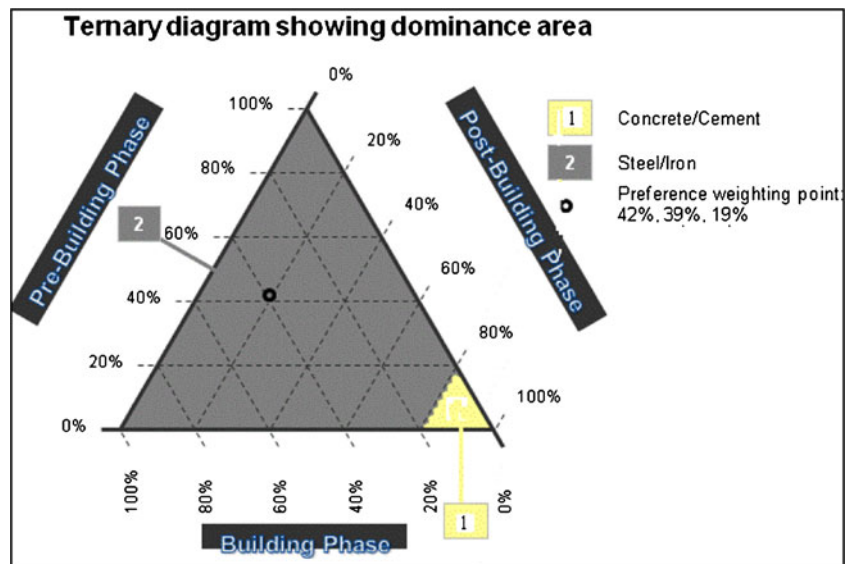
Fig. 16 Scores of impact categories for each alternative

Fig. 17 Sensitivity analysis of life cycle phases (*black circle* on diagram is associated with preference weighting points, 42, 39, and 19 %, which are the current result of pairwise comparison by experts)

different stakeholders, communities, or countries may perceive impact differently. Some issues may also only exist in certain parts of the sector, for example forced labor may exist in large-scale production, but not in small-scale. It is therefore difficult to generalize for an entire sector or value chain. The result of sensitivity analysis state that the sensitivity of the ranking to the (importance) weights of stakeholders is greater than the sensitivity to the weights of life cycle phases. This indicates that analyst should pay more attention to determining importance weights of stakeholders.

4.4.2 Evaluation of the study

Completeness A subset of—not all of—subcategories suggested by UNEP/SETAC have been addressed in the case

study. In fact, a preliminary filtration was performed on the suggested subcategories by UNEP/SETAC and a subset of them was used for hot spot analysis. In hot spot analysis, a secondary filtration was carried out on them, and a final list of subcategories was selected for pairwise comparison in the impact assessment phase. These filtrations were due to some reasons including lack of data, irrelevancy, and insignificancy.

Consistency Appropriateness of the different methodological choices in each phase of the case study previously was discussed. Here, we add this point that since the proposed methodology and data collection have no statistical foundation, no statistical verification and validation are necessary.

Fig. 18 Sensitivity analysis of stakeholders (*black circle* on diagram is associated with preference weighting points, 21, 48, and 31 %, which are the current result of pairwise comparison by experts)
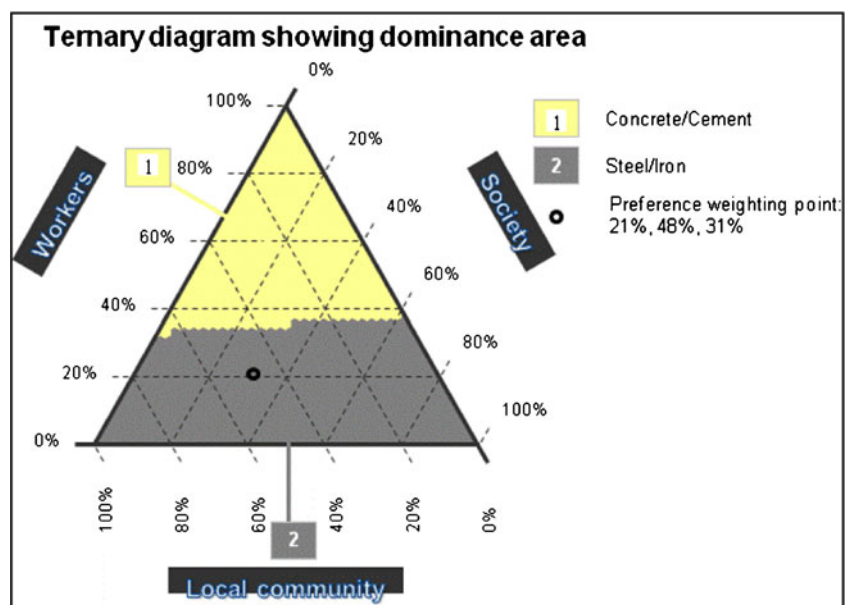
4.4.3 Conclusions and recommendations

Conclusions From a social life cycle perspective, steel performs well when compared to concrete. In highlighting steel's potential to contribute to building designs with much improved overall socio-economic performance, there is no intention to imply that steel is "better" than concrete. Concrete has its distinctive properties and advantages in particular circumstances. It presents opportunities to improve eco-efficiency of production (for example, using green cement production technologies, using wastes from other industries as additives or alternative fuels in cement production, or using pozzolana in concrete production), and it can be used in creative ways to improve the life cycle socio-economic performance of buildings (for example, recycling of concrete wastes and reusing them). The life cycle social performance of concrete can be improved by developing systems which promote the recovery of concrete during deconstruction. Good management leverages the fact that concrete can be crushed, recycled, and reused. Managerial practices that enhance recovery of concrete should be encouraged. However, as seen in inventory results (see Table A1 in the Electronic supplementary material), none of these opportunities are used currently in the presented case. Only some research projects were initiated to address these opportunities. In fact, the conduct of the companies involved in the product chain and the way they organize and manage their business are responsible for these deficiencies.

On the other hand, life cycle social performance of steel can be improved by improving working conditions (health and safety, payment, job security, etc), especially in extraction stage. Bad working conditions of coal miners are mainly related to the conduct of the mining companies and less with mining processes in general. These findings pointed out that social impacts are primarily connected to the conduct of companies and less with processes in general. This confirms the results of Dreyer et al. (2006). The proposed approach aims to reveal product/process improvement potentials to facilitate companies to act socially compatible.

Recommendations Specific recommendations for the two building materials were stated in the subsections "important social findings" and "conclusions" by introducing improvement opportunities. Here, a general recommendation is made for applying S-LCA based on these specific recommendations, the previous knowledge about S-LCA, and the knowledge gained during the case study. The important point is that comparison between the social impacts of different alternatives is not much helpful without considering the improvement opportunities that are being identified. According to UNEP/SETAC guideline, the ultimate objective for conducting an S-LCA is to promote improvement of social conditions and of the overall socio-economic performance of a product throughout its life cycle for all of its stakeholders. Opportunities are

reflected in the laws, regulations, and standards that are being determined by government and the policies that are being made by the companies as well as the management practices. Life cycle assessments of the social impacts of different alternatives contribute to sound decision making, but S-LCA must be placed in the context of policy making and performance management and improvement if it is to be effective. The outcomes of the modeling exercise will help to create a much better context for deliberations on what industry and government can do to reduce the overall social impacts of materials.

5 Conclusions and future research directions

Methodologies for the implementation of S-LCA are still under development. In this paper, authors showed that the development of an approach for material comparison is well underway, but many challenges still persist. Especially weighting and scoring of social issues remain a challenge. The case study presented in this article shows that the evaluation of social impacts is possible, even if the assessment is always affected by subjective value systems. The simple and intuitive result presentation helps to identify the major issues in life cycles and product systems. Furthermore, it was concluded that after a generic study, a company-specific assessment would be preferred to be conducted since social issues are strongly linked to the performance of the company management. The case study investigated the social implications surrounding the life cycle of concrete and steel, and after extensive data collection, assessment, and interpretation, it was concluded that the building material with the least social impact is steel.

Proposed method will be able to identify the hotspots of issues that are most urgent to be addressed to approach a more socially sustainable product. Further research and case study applications are necessary to elaborate the proposed methodology. On a more general note, it will be interesting to apply the method of S-LCA as developed by the UNEP/SETAC group to other building materials, especially materials with a more complex life cycle will be a challenge. As with any new method, getting experience on data collection and evaluation,

Table 8 Contributions of this paper

Contribution to methodology	Contribution to implementation
Developing methods for screening stage in life cycle inventory analysis phase of S-LCA, i.e., MFA and experts judgment	The first comprehensive S-LCA of building materials
Developing new approaches for life cycle impact assessment phase of S-LCA, i.e., pairwise comparison, AHP, and group decision making	Comparison of two building materials

building a data stock, integrating the method in life cycle software, and finding ways for effective communication of results are important steps until integrating S-LCA in routine, recognized decision support. Future research may focus on scoring, weighting, and normalization in S-LCA. More discussion on determination of scores for each inventory indicators in each life cycle stage in S-LCA can be made.

During the case study, it was clear that even though there was a successful assessment with an evident result, the UNEP/SETAC guideline needs more fine-tuning in order to be successful when comparing different products or materials. "UNEP/SETAC guideline for S-LCA" provided several suggestions for detailing and fine-tuning of the S-LCA methodology. However, experience of authors in this study showed two major areas that need more fine-tuning specifically for comparative studies. (1) Comparison between different alternatives essentially needs a clear basis for assessing and comparing impacts. However, generally there is no such basis for social impacts. So, characterization models should be developed that are able to translate inventory results to impacts in a comparative way. Most of the characterization models in S-LCA developed to this time is in the form of scoring systems. Some of them are reviewed in Section 3.1. Characterization model presented in this paper is also a scoring system based on pairwise comparisons. However, more researches are needed to develop other characterization models and to compare the result of them to each other and to explain suitable application of each. (2) The second challenge emerged here. As discussed in Section 3.1, the abovementioned characterization models are not able to link the impact results to the functional unit. Thus, there are no "impacts per FU," and we are not able to scale the results for other systems with different capacities (as we can do in E-LCA). This fact limits the use of the results to a specific case, and no inference can be made about other cases. More researches are needed to solve this challenge.

Table 8 summarizes the contributions of this paper. It clearly states that the contribution is twofold: methodology and implementation.

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